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Kerr Blackhole Perturbation and Metric Reconstruction Problem in a Horizon-Penetrating Coordinates

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We investigate the Teukolsky equations in horizon-penetrating coordinates to study the behavior of perturbation waves crossing the outer horizon. For this purpose, we use the null ingoing/outgoing Eddington-Finkelstein coordinates. We find that the radial equation is a confluent form of Heun's differential equation in both ingoing/outgoing coordinates, with three singularities. The radial function satisfies the physical boundary conditions without imposing any regularity conditions. We also observe that the Hertz-Weyl scalar equations preserve their angular and radial signatures in these coordinates. Using the angular equation, we construct the metric perturbation for a circularly orbiting perturber around a black hole in Kerr spacetime. Furthermore, we complete the missing metric pieces due to the mass and angular momentum perturbations. We also provide an explicit formula for the metric perturbation as a function of the radial part, its derivative, and the angular part of the solution to the Teukolsky equation.

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